PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

United States Patent and Trademark Office
(Box PCT)
Crystal Plaza 2
Washington, DC 20231
ÉTATS-UNIS D'AMÉRIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 08 July 1999 (08.07.99)	
International application No. PCT/GB98/03401	**Applicant's or agent's file reference** WBH
International filing date (day/month/year) 12 November 1998 (12.11.98)	**Priority date** (day/month/year) 14 November 1997 (14.11.97)
Applicant CRUICKSHANK, David, George, Melville et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International Preliminary Examining Authority on:

17 May 1999 (17.05.99)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was

[ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland**	Authorized officer S. Mafla

PATENT COOPERATION TREATY

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INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
WBH		
International application No.	International filing date *(day/month/year)*	(Earliest) Priority Date *(day/month/year)*
PCT/GB 98/ 03401	12/11/1998	14/11/1997
Applicant		
THE UNIVERSITY OF EDINBURGH et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

a. With regard to the **language,** the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

[ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

[ ] contained in the international application in written form.

[ ] filed together with the international application in computer readable form.

[ ] furnished subsequently to this Authority in written form.

[ ] furnished subsequently to this Authority in computer readble form.

[ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

[ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**

[ ] the text is approved as submitted by the applicant.

[X] the text has been established by this Authority to read as follows:

FAST ACQUISITIONS OF DIRECT SECQUENCE SPREAD SPECTRUM SIGNALS

5. With regard to the **abstract,**

[X] the text is approved as submitted by the applicant.

[ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 3

[X] as suggested by the applicant.

[ ] None of the figures.

[ ] because the applicant failed to suggest a figure.

[ ] because this figure better characterizes the invention.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 98/03401

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04B1/707

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	STIRLING-GALLACHER R A ET AL: "A fast acquisition technique for a direct sequence spread spectrum signal in the presence of a large Doppler shift" 1996 IEEE 4TH INTERNATIONAL SYMPOSIUM ON SPREAD SPECTRUM TECHNIQUES AND APPLICATIONS PROCEEDINGS. , PROCEEDINGS OF ISSSTA'95 INTERNATIONAL SYMPOSIUM ON SPREAD SPECTRUM TECHNIQUES AND APPLICATIONS, MAINZ, GERMANY, 22-25 SEP, 1996, pages 156-160 vol.1, XP002102966 ISBN 0-7803-3567-8, 1996, New York, NY, USA, IEEE, USA cited in the application see the whole document --- -/--	1-12

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 May 1999	01/06/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Wanzeele, R

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 629 929 A (BLANCHARD SCOTT D ET AL) 13 May 1997 see column 3, line 33 - column 4, line 52; claims 7,10; figure 2	1-12
E	EP 0 892 528 A (NOKIA MOBILE PHONES LTD) 20 January 1999 see claims 1-20	1,10
X,P	GRANT P M ET AL: "Doppler estimation for fast acquisition in spread spectrum communication systems" 1988 IEEE 5TH INTERNATIONAL SYMPOSIUM ON SPREAD SPECTRUM TECHNIQUES AND APPLICATIONS - PROCEEDINGS. SPREAD TECHNOLOGY TO AFRICA , PROCEEDINGS OF ISSSTA'98 INTERNATIONAL SYMPOSIUM ON SPREAD SPECTRUM TECHNIQUES AND APPLICATIONS, 2-4 SEP 1998, pages 106-110 vol.1, XP002102967 ISBN 0-7803-4281-X, 1998, New York, NY, USA, IEEE, USA see the whole document	1-12
A	US 5 271 034 A (ABAUNZA JOHN) 14 December 1993 see column 10, line 23 - column 11, line 57; figure 5	1,10
A	WO 96 26579 A (STANFORD TELECOMM INC) 29 August 1996 see page 30, line 18 - page 32, line 14; figure 7	1,10
A	US 5 463 657 A (RICE BART F) 31 October 1995 see column 6, line 65 - column 7, line 18; claim 1; figure 4	1,10

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 98/03401

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5629929 A	13-05-1997	NONE	
EP 0892528 A	20-01-1999	JP 11088229 A	30-03-1999
US 5271034 A	14-12-1993	NONE	
WO 9626579 A	29-08-1996	AU 5416496 A	11-09-1996
US 5463657 A	31-10-1995	NONE	

M·H

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PATENT COOPERATION TREATY

PCT

REC'D 11 FEB 2000
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INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
WBH		
International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/GB98/03401	12/11/1998	14/11/1997
International Patent Classification (IPC) or national classification and IPC H04B1/707		
Applicant THE UNIVERSITY OF EDINBURGH et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 6 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☒ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☒ Certain documents cited
   - VII ☒ Certain defects in the international application
   - VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
17/05/1999	09
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Bauer, F Telephone No. +49 89 2399 2737

Form PCT/IPEA/409 (cover sheet) (January 1994)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB98/03401

I. Basis of the report

1. This report has been drawn on the basis of (*substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments.*):

Description, pages:

1-15 as originally filed

Claims, No.:

1-12 as originally filed

Drawings, sheets:

1/5-5/5 as originally filed

2. The amendments have resulted in the cancellation of:

☐ the description, pages:
☐ the claims, Nos.:
☐ the drawings, sheets:

3. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

4. Additional observations, if necessary:

II. Priority

1. ☐ This report has been established as if no priority had been claimed due to the failure to furnish within the prescribed time limit the requested:

   ☐ copy of the earlier application whose priority has been claimed.

   ☐ translation of the earlier application whose priority has been claimed.

2. ☐ This report has been established as if no priority had been claimed due to the fact that the priority claim has been found invalid.

Thus for the purposes of this report, the international filing date indicated above is considered to be the relevant date.

3. Additional observations, if necessary:

see separate sheet

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-12
	No:	Claims	
Inventive step (IS)	Yes:	Claims	
	No:	Claims	1-12
Industrial applicability (IA)	Yes:	Claims	1-12
	No:	Claims	

2. Citations and explanations

see separate sheet

VI. Certain documents cited

1. Certain published documents (Rule 70.10)

and / or

2. Non-written disclosures (Rule 70.9)

see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:

see separate sheet

Re Item II

The priority document was not available during examination and could therefore not be checked (see also Item VI of the present opinion).

Re Item V

1. Reference is made to the following documents:

   D1: STIRLING-GALLACHER R A ET AL: 'A fast acquisition technique for a direct sequence spread spectrum signal in the presence of a large Doppler shift' 1996 IEEE 4TH INTERNATIONAL SYMPOSIUM ON SPREAD SPECTRUM TECHNIQUES AND APPLICATIONS PROCEEDINGS. , PROCEEDINGS OF ISSSTA'95 INTERNATIONAL SYMPOSIUM ON SPREAD SPECTRUM TECHNIQUES AND APPLICATIONS, MAINZ, GERMANY, 22-25 SEP, 1996, pages 156-160 vol.1, ISBN 0-7803-3567-8, 1996, New York, NY, USA, IEEE, USA cited in the application

   D2: US-A-5 305 286.

   The document D2 was not cited in the international search report.

2. a) D1 (Fig. 3 and abstract) discloses a communication terminal for use in a code division multiple access system, comprising a plurality of correlating means (top of fig. 3), each for correlating a part of a spreading code sequence relating to a signal to be acquired, and FFT means for operating on the output of the correlating means.

   b) The difference between D1 and the subject-matter of claim 1 lies in the use of a **zero-padded** FFT instead of a standard FFT.

   c) The problem to be solved by the invention may be regarded as improving the existing device. In D1, page 157, right column, second paragraph, it is indicated that "the output signal of the FFT is reduced when the input frequency is between two bins of the FFT". The passage written in the present application on page 6, lines 5-8, explaining that zero padding the FFT increases frequency resolution

and improves detection performance for frequencies between two bins of the FFT, refers to general knowledge (see e.g. D2, column 6, lines 34-41).
Therefore, it would ne obvious to the skilled man, knowing from D1 where to improve the device, to arrive at the claimed invention.

d) Therefore, the subject matter of **claim 1** is not inventive (Article 33 (3) PCT).

e) For the same reasons, the subject matter of independant **claim 10** related to a method is not inventive.

3. Claims 2-9 and 11-12 consist merely in the juxtaposition or association of known devices (either as such or from D1) or characteristics functioning in their normal way and not producing any non-obvious working inter-relationship.
Therefore, the subject matter of **claims 2-9 and 11-12** is not inventive.

Re Item VI

1. Reference is made to the following documents:
   D3: GRANT P M ET AL: 'Doppler estimation for fast acquisition in spread spectrum communication systems' 1988 IEEE 5TH INTERNATIONAL SYMPOSIUM ON SPREAD SPECTRUM TECHNIQUES AND APPLICATIONS - PROCEEDINGS. SPREAD TECHNOLOGY TO AFRICA , PROCEEDINGS OF ISSSTA'98 INTERNATIONAL SYMPOSIUM ON SPREAD SPECTRUM TECHNIQUES AND APPLICATIONS, 2-4 SEP 1998, pages 106-110 vol.1, ISBN 0-7803-4281-X, 1998, New York, NY, USA, IEEE, USA
   D4: EP-A-0 892 528.

2. Document **D3**, made available to the public on the 4th of september 1997, i.e. before the filing date of the present international application, but after its claimed priority date, is considered to be very relevant with regard to **compliance with Art. 32(2) and (3) of claims 1-12** of the present international application **if said claimed priority is not valid** (see also Item II of the present opinion).

3. Document **D4** (especially claims 1-20), published on the 20.01.1999, i.e. after the

priority date of the present international application, but with a priority date being the 17.07.1997, i.e. anterior to the claimed priority of the present international application, is considered to be **relevant with regard to novelty of claims 1-12** of the present international application **in the regional phase.**

Re Item VI

The claims are not in the two-part form in accordance with Rule 6.3(b) PCT, which in the present case would be appropriate, with those features known in combination from the prior art (document D1) being placed in a preamble (Rule 6.3(b)(i) PCT) and with the remaining features being included in a characterising part (Rule 6.3(b)(ii) PCT).

Re Item VII

It seems that on page 13, line 7, it should read "and that" instead of "andthat".

PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H04J 13/02

A2

(11) International Publication Number: **WO 99/26370**

(43) International Publication Date: 27 May 1999 (27.05.99)

(21) International Application Number: PCT/GB98/03401

(22) International Filing Date: 12 November 1998 (12.11.98)

(30) Priority Data:
9724048.5 14 November 1997 (14.11.97) GB

(71) Applicant *(for all designated States except US)*: THE UNIVERSITY OF EDINBURGH [GB/GB]; Old College, South Bridge, Edinburgh EH8 9YL (GB).

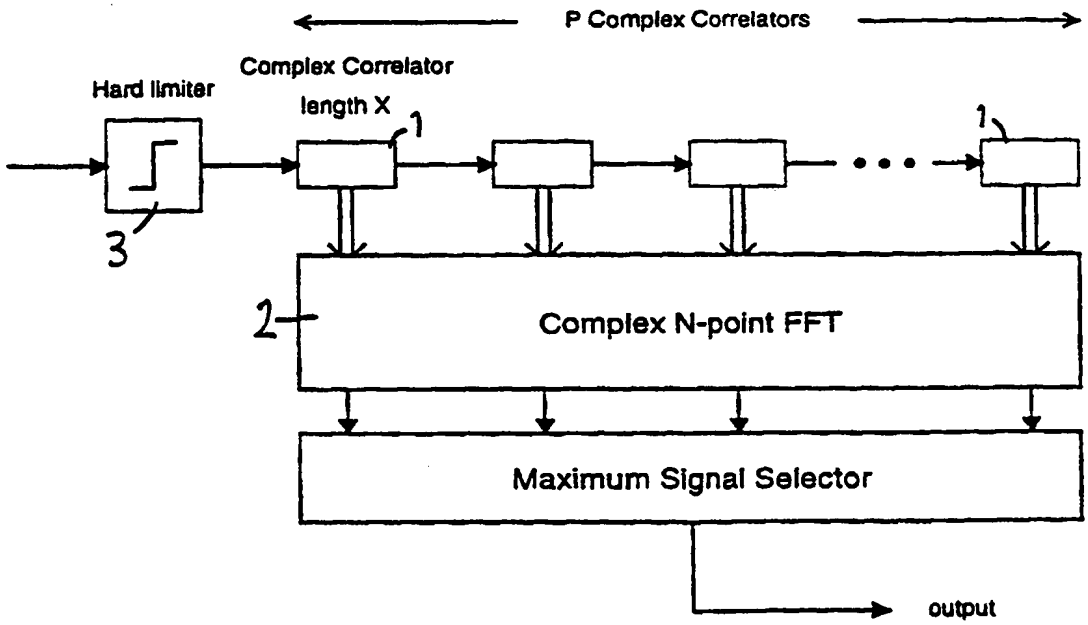
(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: CRUICKSHANK, David, George, Melville [GB/GB]; 32/6 Bernard Terrace, Edinburgh EH8 9NX (GB). SPANGENBERG, Sascha, Marcus [DE/GB]; Top Flat Right, 81 Comely Bank Avenue, Edinburgh EH4 1EU (GB).

(74) Agent: HANSON, William, Bennett; J.Y. & G.W. Johnson, Kingsbourne House, 229–231 High Holborn, London WC1V 7DP (GB).

(81) Designated States: JP, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: COMMUNICATIONS TERMINAL AND OPERATING METHOD



(57) Abstract

A non–coherent technique employs a zero padded FFT for the fast acquisition of direct sequence spread spectrum signals in the presence of large Doppler shifts. The application of a FFT to code acquisition results in decreased acquisition time, and can improve the probability of detection. A set of partial correlators (1) and a zero padded FFT (2) are used to reduce the search region for code acquisition whilst maintaining good frequency resolution for Doppler offset. This approach will prove most pertinent in future reconfigurable terminals.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

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COMMUNICATIONS TERMINAL AND OPERATING METHOD

Background to the Invention

The present invention relates to a communications terminal and a method of operating a communications terminal.

The inflexibility of frequency division multiple access and time division multiple access techniques has resulted in the development of new systems based on the uncoordinated spread spectrum concept. In these new systems, the bits of slow speed data traffic from each subscriber are multiplied by a high chip rate spreading code, forcing each low bit rate (narrowband) data signal to fill a wide channel bandwidth. Many subscribers can then be accessed by allocating a unique, orthogonal spreading code to each. This constitutes a code division multiple access (CDMA) system. In the receiving terminal, the desired signal is detected by correlation against a local reference code which is identical to the particular spread spectrum code employed prior to transmission.

Rapid initial code acquisition and re-acquisition is crucial in CDMA communications. Doppler or local oscillator offsets can lead to frequency uncertainty which make this task particularly difficult. Existing strategies for code acquisition are single and multiple dwell detectors, matched filters, sequential detection and parallel detectors. In the presence of frequency uncertainty, the most common approach is to sequentially search all code phases over the range of anticipated frequency offsets. This brute force approach is laborious and can lead to large acquisition times.

Current second generation mobile communication systems cannot provide sufficient capacity to support the future demands of increased subscribers and higher data rates for multimedia communications. Third generation systems will be required to provide multiple access schemes which are capable

of flexible data rates and variable services. However, it will considerably aid the acceptance of third generation systems if existing standards, infrastructures and components can be reused or reconfigured.

One common way of acquiring a direct sequence spread spectrum (DS-SS) signal is through the use of an energy detector at the output of the despreader. This approach works by tuning the code phase and frequency offset of a complex matched filter over the range of possible phase and frequency offsets anticipated in the system. When the phase of the desired spreading sequence (usually measured in terms of code chips) and local oscillator frequency offset are within specified limits, the detector will produce an output which exceeds some threshold and the system will register the presence of the desired user. This initial acquisition will then trigger a verification loop which confirms the presence of the desired code sequence and subsequently a tracking loop which attempts to continuously maintain close alignment between the two code sequences in order to track any fluctuations. If the desired spreading sequence phase and frequency offset are not within the limits, the output of the detector will not exceed the threshold, and the search for initial acquisition will continue.

The number of possible search bins will be determined by the product of the number of possible code phase offsets (typically a half chip search is employed over the entire sequence), and the total range of possible Doppler offsets. The width of each Doppler bin is in turn determined by the frequency response of the complex correlator, thus yielding a 2-dimensional search plane as depicted in Figure 1. The acquisition cells system sequentially searches this grid by aligning the reference code phase and frequency offset to the centre of each cell. The time required in order to obtain an initial acquisition will therefore depend directly on the number of cells in the search region. For systems with long spreading codes, which might experience large Doppler offsets,

this acquisition time may prove prohibitively large.

We will consider, for example, a system with random codes of length 200, in which the range of possible Doppler shifts is +/- 32 kHz. The normalised frequency response of a complex matched filter (MF) is a function of the Doppler frequency offset Δf, as given below.

$$|H(\Delta f)| = \frac{1}{M} \frac{\sin(M\pi \Delta f T_c)}{\sin(\pi \Delta f T_c)} \qquad (1)$$

In (1), M is the length of the spreading code, Δf is the Doppler frequency offset and T_c is the chip duration. Figure 2 depicts the frequency response of a complex MF for a data rate of 8 kHz (M=200, T_c=625 ns). We see that the 3dB bandwidth of the complex MF with these parameters is around 4 kHz. This will result in a total of (200 x 2) x (64/4)=6400 cells which the energy detector must search. It has therefore been proposed, for example in Sust et al, "Rapid Acquisition Concepts for Voice Activated CDMA Communication" IEEE Globecom 90, pp 1820-1828, and in Stirling-Gallacher et al "A Fast Acquisition Technique for a Direct Spread Signal in the Presence of a Large Doppler Shift" IEEE ISSSTA 96, pp 156-160, to introduce a FFT based improvement to the energy detector which will reduce the number of possible cells by evaluating a reduced search space.

By re-examining Figure 1, it would be possible to substantially reduce the acquisition time, if it were possible to search all possible code Doppler cells simultaneously. By employing a FFT block as part of the acquisition system it would be possible to perform this form of search procedure. A block diagram of such a FFT enhanced acquisition system is shown in Figure 3.

The system consists of P complex matched filter correlators 1, each of length X, such that the product X x P equals the code length M. The first correlator will contain the first X chips of the spreading sequence, the second will

contain the next X chips, and so on through the P correlators. The outputs of the P correlators are therefore partial correlation results. These partial results are then passed to a N-point FFT 2, where $N = P$. The processing gain of this receiver is the same as the original energy detector, however if the correlator length X is chosen correctly, the addition of FFT processing allows the simultaneous search of all possible code Doppler shifts.

A specific example should illustrate this more effectively. Continuing with the previous example, where $M = 200$ and $T_c = 625$ ns, in order to increase the bandwidth of the partial correlators to beyond +/- 32 kHz, their length is decreased to X=25. Therefore the number of partial correlators is P=8. If $N = P$ i.e. a 8-point FFT is selected, Figure 4 depicts the output of a maximum signal selector superimposed on all the FFT bin outputs. The bandwidth of the FFT processor has increased, and is much improved over the standard complex correlator. To further increase the bandwidth, the length of the individual correlators should be reduced and the total number of correlators increased correspondingly.

This FFT enhancement will allow all possible code Doppler offsets to be searched simultaneously. However, a scalloping loss can be observed when the Doppler offset falls between two bins of the FFT. This will result in a reduced probability of detection for signals with these Doppler offsets, as compared to signals which occur in the centre of any given bin.

Summary of the Invention

The present invention seeks to improve the acquisition time of a spread spectrum communication system, preferably through the reuse of FFT processing blocks. The approach taken is thought to be particularly applicable to third generation mobile systems, for which reuse and/or reconfiguration of hardware will be an important priority.

According to one aspect of the invention there is provided a communications terminal for use in a code division multiple access system, comprising a plurality of correlating means, each for correlating a part of a spreading code sequence relating to a signal to be acquired, and zero padded Fast Fourier Transform (FFT) means for operating on the output of the correlating means. The inclusion of a zero padded FFT increases the resolution of the FFT processor without increasing the overall bandwidth.

Preferably, the correlating means each comprise a complex matched filter correlator and preferably each correlator is of the same chip length, the product of the chip length of each correlator and the number of correlators being equal to the code length. Good results are obtained if the chip length of each correlator is 25 or less.

Preferably, the terminal includes a hard limiter at the input to the correlating means. This enables the use of cheap digital correlators.

The FFT means may in particular be a complex zero padded FFT processor which preferably has at least twice as many points as the number of correlators and may have four or eight times as many. The output of the FFT means may be supplied to a maximum signal selector for signal acquisition.

According to another aspect of the invention there is provided a method of operating a code division multiple access communications terminal so as to acquire a given signal, comprising correlating the spreading code sequence of the given signal in a plurality of partial correlation operations, and processing the partial correlation results using a zero padded Fast Fourier Transform (FFT).

Preferably, prior to the correlation step, the signal is passed through a hard limiter, and preferably, after the FFT step, the maximum signal present is selected to acquire the

given signal.

The invention utilises a FFT to simultaneously search all possible code Doppler offsets at one time, thus reducing the 2-dimensional search problem to a 1-dimensional search for code phase. By zero padding the FFT increased frequency accuracy is provided, which ensures that desired signals with Doppler offsets which lie between two bins of the FFT are not masked.

Brief Description of the Drawings

The present invention will now be described in more detail, by way of example only, with reference to the accompanying drawings, in which:-

Figure 1 is a diagram showing the search region for a conventional CDMA energy detector acquisition system;

Figure 2 shows the frequency response of a complex matched filter correlator;

Figure 3 is a block circuit diagram of an FFT based acquisition systems adapted from that of Sust et al;

Figure 4 shows the output of the system shown in Figure 3;

Figure 5 shows the output of a system according to an embodiment of the invention;

Figure 6 is a graph of probability of false alarm in the system of Figure 3 and in embodiments of the invention;

Figure 7 is a graph of probability of detection in the system of Figure 3;

Figure 8 is a graph as Figure 7, but also relating to embodiments of the invention; and

Figures 9 and 10 are graphs of mean acquisition time in the system of Figure 3 and in an embodiment of the invention, for two different respective false alarm penalty values.

Detailed Description of the Preferred Embodiments

Figure 5 shows the response when a 16-point FFT is inserted in the system shown in Figure 3, with the maximum signal selector superimposed. The number of correlators $P = 8$, and their length $X = 25$, remain unchanged. It can be seen that effectively there are more FFT output lobes in the same range of Doppler frequency uncertainty and therefore the scalloping loss is reduced.

In order to quantify the difference this padding effects, consider a signal with a Doppler offset of 28 kHz. This lies directly between two bins of the 8-point FFT shown in Figure 4. The normalised magnitude response at this offset is approximately 0.46. However, when the 16-point padded FFT (Figure 5) is employed the normalised response increases to approximately 0.7. It is clear that further levels of padding will further reduce the scalloping loss which occurs, however the rate of improvement decreases rapidly with increasing amounts of padding. For this scheme it is apparent that no further increase will be seen above a 64-point FFT.

The approach discussed above is an improvement of the swivelling correlator described by Sust et al. In Sust et al, the inclusion of FFT processing was seen as an additional burden on the processor, and therefore the FFT was kept as small as possible. Implementing a large FFT will not necessarily present such a problem in third generation terminals.

The earlier discussion neglected the impact of the hard limiter 3 which is placed at the input of the correlators. This has the effect of constraining the input to the first correlator to be either +/- 1. This causes the statistics of the signal at the input to the correlators to be binomial, and when no signal is present this limiter constrains the variance of the noise. If the interference statistics can be assumed to be Gaussian, the hard limiter will result in a loss of

approximately 2 dB. The simulation results presented below confirm this. In lightly loaded CDMA channels the interference statistics cannot be assumed to be Gaussian, and this loss will probably increase further. A worst case was highlighted by Sust et al, in which there are only two users with unbalanced power. The limiter will have the effect of suppressing the weaker user, although receiver dither can be successfully used to combat this problem.

Despite these limitations, the limiter 3 is still attractive from a digital signal processing perspective. The use of hard limiting allows single bit quantisation, and therefore cheap digital correlators can be employed as opposed to more costly analogue or high resolution digital processors. The simulation results presented herein include the impact of the hard limiter, however the more detailed problems highlighted in the above paragraph are not considered.

In order to quantify the possible improvements which can be gained by employing a padded FFT, some approximate theoretical expressions for the performance of the FFT based acquisition system are derived below. In particular, three performance measures are considered: false alarm probability, probability of detection and mean acquisition time.

A. Probability of false alarm.

In this section, the probability of false alarm, P_{fa}, is derived, assuming that the desired signal is not present. The false alarm probability will depend upon the statistics of the noise at the input to the detector, and upon the threshold level employed in the detector. As a result of the limiter at the input to the correlators, the noise will have a binomial distribution, with unit variance and zero mean. If the correlators are assumed to be sufficiently long, the central limit theorem can be applied to show that the signals at the input to the FFT are uncorrelated and have Gaussian statistics. If each correlator is of length X, then each

output will have variance X and mean zero. If there are P correlators, then the outputs of a zero padded N-pt FFT (i.e. $N > P$) will have variance $PX (= M$, the code length) and zero mean. The magnitude of the outputs of the FFT are used in the detector - these amplitude signals will be Rayleigh distributed with probability density function (pdf) given by

$$p(r) = \frac{r}{M} e^{\frac{-r^2}{2M}} \qquad (2)$$

and cumulative distribution function (cdf)

$$F(r) = 1 - e^{\frac{-r^2}{2M}} \qquad (3)$$

The probability that any one FFT output is greater than some threshold level t, is given by

$$P[output > t] = e^{\frac{-r^2}{2M}} \qquad (4)$$

All of the FFT outputs have the same distribution, and therefore the probability of any one of the N outputs exceeding the threshold (and hence the probability of false alarm) is given simply by

$$P_{fa} = 1 - (1 - e^{\frac{-r^2}{2M}})^N \qquad (5)$$

B. Probability of detection.

The derivation of the probability of detection follows that of the false alarm probability. In this case it is assumed that the desired signal and corrupting noise are present at the input to the acquisition system. Again the noise at the inputs to the FFT is assumed to be decorrelated and Gaussian with variance X and mean zero. If the mean desired signal level at the input to the acquisition system is X, then the mean signal level (in bin 0 at frequency 0 Hz) will be $PX\alpha = M\alpha$. The output noise variance is M as before. At the output of the FFT, the amplitudes of the signals are taken, thus the statistics of the output of some FFT bin i are

Rician, with pdf given by

$$p_i(r) = \frac{r}{M} e^{-\left(\frac{r^2+s_i^2}{2M}\right)} I_0\left(\frac{rs_i}{M}\right) \qquad (6)$$

where I_o is the zero-th order modified Bessel function, and s_i is the summation of the mean of the signals on the inphase and quadrature branches for bin i,

$$s_i^2 = m_I^2 + m_Q^2 \qquad (7)$$

The cumulative distribution function of the Rice distribution is given by

$$F(r) = 1 - e^{-\left(\frac{r^2+s_i^2}{2M}\right)} \sum_{m=0}^{\infty} \left(\frac{s_i}{r}\right)^m I_m\left(\frac{rs_i}{M}\right) \qquad (8)$$

The probability that the amplitude of bin i is greater than some threshold t is given by

$$P^i[output > t] = e^{-\left(\frac{r^2+s_i^2}{2M}\right)} \sum_{m=0}^{\infty} \left(\frac{s_i}{r}\right)^m I_m\left(\frac{rs_i}{M}\right) \qquad (9)$$

Signal acquisition is assumed if any of the output bins is greater than the threshold. Each of the N FFT output bins has the same distribution, and therefore the probability of any one of the N outputs exceeding the threshold (and hence the probability of detection) will be given by

$$P_d = 1 - P_{no\ detection} \qquad (10)$$

$$P_d = 1 - \prod_{i=0}^{N} (1 - P^i[output > t]) \qquad (11)$$

C. Mean acquisition time.

The present analysis considers a single dwell detector. The acquisition model can be summarised as follows. Suppose there are q cells to be searched (through a combination of both code phase and Doppler uncertainty). Assume that if a hit is detected (i.e.the magnitude of any output of the FFT

is greater than some threshold), the system goes into a verification mode that may include an extended dwell period and a code tracking loop period. The false alarm penalty of entering the verification mode when the desired signal is not present is modelled as $K\tau_d$, where the dwell or integration time is given by τ_d. The mean acquisition time for such a single dwell system has been derived as

$$\overline{T}_{acq} = \frac{(2-P_d)\,(1+KP_{fa})}{2P_d}\,(q\tau_d) \qquad (12)$$

In order to aid comparison between different systems, the mean acquisition time is often normalised to the integration time τ_d as follows

$$\frac{\overline{T}_{acq}}{\tau_d} = \frac{(2-P_d)\,(1+KP_{fa})}{2P_d}\,(q) \qquad (13)$$

The mean acquisition time results presented below use values of P_{fa} and P_d derived from simulation, for a selection of false alarm penalty values.

The theoretical performance of the FFT acquisition scheme of the invention is now compared with Monte Carlo simulation results. The simulations investigate the effect of using increasingly larger padded FFTs on the three variables for which the theoretical values were derived above. For simplicity and consistency, the same system parameters are used as in the previous examples. To recap, a data rate of 8 kHz is assumed, with random codes of length M = 200 which leads to a chip period of 625 ns. The partial correlators are of length X = 25, which means that there are 8 inphase and quadrature inputs to the FFT block. The received sequence with the carrier offset of 28 kHz which was highlighted earlier is also considered below. This will clearly illustrate the improvement achieved by zero padding in the FFT.

A. False alarm probability.

The first set of results concerns the probability of false alarm. Figure 6 presents the results from Monte Carlo simulation of four different FFT sizes. The acquisition system was simulated with only noise present, and the simulation was terminated when either the equivalent of 1 million data bits had been transmitted, or 500 false alarm errors were collected.

The dotted lines in Figure 6 depict the theoretical false alarm probability as computed by (5) against the threshold level in the detector. It is apparent that increasing the FFT size results in an increase in the probability of false alarm, since with more output bins there is an increased probability of any one individual bin exceeding the threshold. The theoretical curves assume that each of the N output bins of the FFT are independent and equally likely to exceed the threshold. However, there are only 8 non-zero and independent inputs to the FFT, which means that the output bins will not be truly independent. This effect is seen in the "saturation" observed in the simulated points - as the FFT size is successively increased the false alarm probability quickly reaches a maximum value. It will become apparent from the next set of results that it is possible to compensate for the increased probability of false alarm by improving the probability of detection.

B. Probability of detection.

The theoretical probability of detection can be computed from (11) through the Markum Q function. A Q function evaluation algorithm was used to evaluate the theoretical curves for Figures 7 and 8. The Markum Q function is the infinite sum in (11), i.e.

$$Q\left(\frac{s_i}{\sigma}, \frac{t}{\sigma}\right) = e^{-\left(\frac{r^2+s_i^2}{2M}\right)} \sum_{m=0}^{\infty} \left(\frac{s_i}{r}\right)^m I_m\left(\frac{r s_i}{M}\right) \qquad (14)$$

The algorithm computes the value of $Q(\cdot,\cdot)$ by using a truncated series approximation. Figure 7 compares the theoretical and simulated values of probability of detection for an 8 point FFT for three threshold values at a Doppler offset of 28kHz. The graph shows that as the threshold value is decreased the probability of detection is increased, andthat as the signal-to-noise ratio (SNR) increases the probability of detection also increases.

It is also possible to see the impact of hard limiting on the performance of the detector. The limiter quantises the received signal into either +/- 1 values, so that the individual outputs of the partial correlators have integer, rather than real values. Therefore, the rotating phasors which are observed at the partial correlator outputs are quantised in value, rather than following their theoretically continuous pattern. Provided the correlators are sufficiently long, and the noise is dominant, this quantisation error will be small. When Gaussian noise corrupts the input to a hard limiter, it has the effect of linearising the limiter's operating characteristic. At higher SNR values, the characteristic is more nonlinear (when no noise is input the limiter characteristic is extremely nonlinear), so that the impact of the quantisation is only seen at higher SNR values. The theoretical curves, shown dotted in Figure 7, do not include the operation of the limiter to illustrate the loss in performance due to this quantisation error.

The next set of results considers the improvement which can be achieved by zero padding the FFT to increase the frequency resolution. Figure 8 contrasts four FFT sizes, for a detection threshold of 60. As was predicted, the probability of detection increases as the FFT size increases. However, a similar saturation effect can be seen as was observed in the

false alarm probability results. This occurs because the theoretical curves assume that each output bin of the FFT has an equal probability of containing the desired signal, however the outputs of a padded FFT are weakly dependent and this is evidenced in the lack of improvement in the detection probability above FFT sizes of around 64. Despite this saturation effect, the addition of zero--padding to the FFT has improved the probability of detection by a factor of approximately 3. Again, the Doppler offset is 28kHz and the dotted theoretical curves neglect the effect of hard limiting.

C. Mean acquisition time.

The mean acquisition results use (13) with values for P_d and P_{fa} derived from the earlier simulation studies. The results presented here consider the two false alarm penalty values, $K = 1, 50$. These values represent two different extremes, and so help to illustrate the dependence between the increased false alarm rate and improved probability of detection.

Figures 9 and 10 depict the mean acquisition time as a function of SNR, with $K = 1$ and $K = 50$, respectively. It is apparent that the use of the larger (padded) FFT results in a decrease in the mean acquisition time for both false alarm penalty values. The improvement is most dramatic for higher threshold values. With a detection threshold of 60 and $K = 1$, the mean acquisition time for the 64 point FFT is approximately one third that of the 8 point FFT. However, for a threshold of 40 with $K = 50$ there is little difference in mean acquisition time between the two FFT sizes. Figure 10 shows that at high SNR values it would be preferable to impose a larger detection threshold, since the large value of false alarm penalty makes false alarms more dominant in the acquisition time.

The present invention thus provides an improved acquisition scheme for direct sequence spread spectrum

communications. The technique reuses FFT hardware available from other functions to simultaneously search all code Doppler offsets, and thereby reduce the mean acquisition time. The reuse of hardware (for example OFDM receiver hardware) in a manner similar to this will prove vital to the success of future third generation communication terminals.

When the code Doppler shift of the desired sequence falls between two bins of the FFT, zero padding of the FFT block can lead to reductions in the acquisition time. Zero padding results in a slight increase in the false alarm probability, however this is compensated for by an increase in the probability of detection.

The method of the invention holds promise for implementation in future reconfigurable terminals in mobile and satellite communications systems.

CLAIMS

1. A communications terminal for use in a code division multiple access system, comprising a plurality of correlating means, each for correlating a part of a spreading code sequence relating to a signal to be acquired, and zero padded Fast Fourier Transform (FFT) means for operating on the output of the correlating means.

2. A communications terminal according to claim 1, wherein the correlating means each comprise a complex matched filter correlator.

3. A communications terminal according to claim 2, wherein each correlator is of the same chip length, the product of the chip length of each correlator and the number of correlators defining the length of the spreading code.

4. A communications terminal according to claim 3, wherein the chip length of each correlator is 25 or less.

5. A communications terminal according to any preceding claim, including a hard limiter at the input to the correlating means.

6. A communications terminal according to any preceding claim, wherein the FFT means is a complex zero padded FFT processor having at least twice as many points as the number of correlating means.

7. A communications terminal according to claim 6, wherein the FFT processor has four times as many points as the number of correlating means.

8. A communications terminal according to claim 6, wherein the FFT processor has eight times as many points as the number of correlating means.

9. A communications terminal according to any preceding claim, wherein the output of the FFT means is supplied to a maximum signal selector for signal acquisition.

10. A method of operating a code division multiple access communications terminal so as to acquire a given signal, comprising correlating the spreading code sequence of the given signal in a plurality of partial correlation operations, and processing the partial correlation results using a zero padded Fast Fourier Transform (FFT).

11. A method according to claim 10, wherein, prior to the correlation step, the signal is passed through a hard limiter.

12. A method according to claim 10 or 11, wherein, after the FFT step, the maximum signal present is selected to acquire the given signal.

Fig. 1

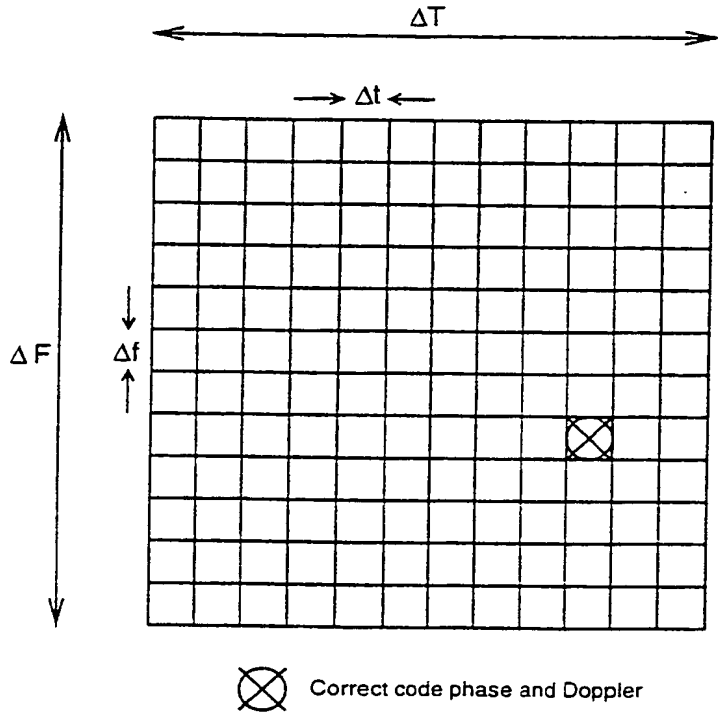
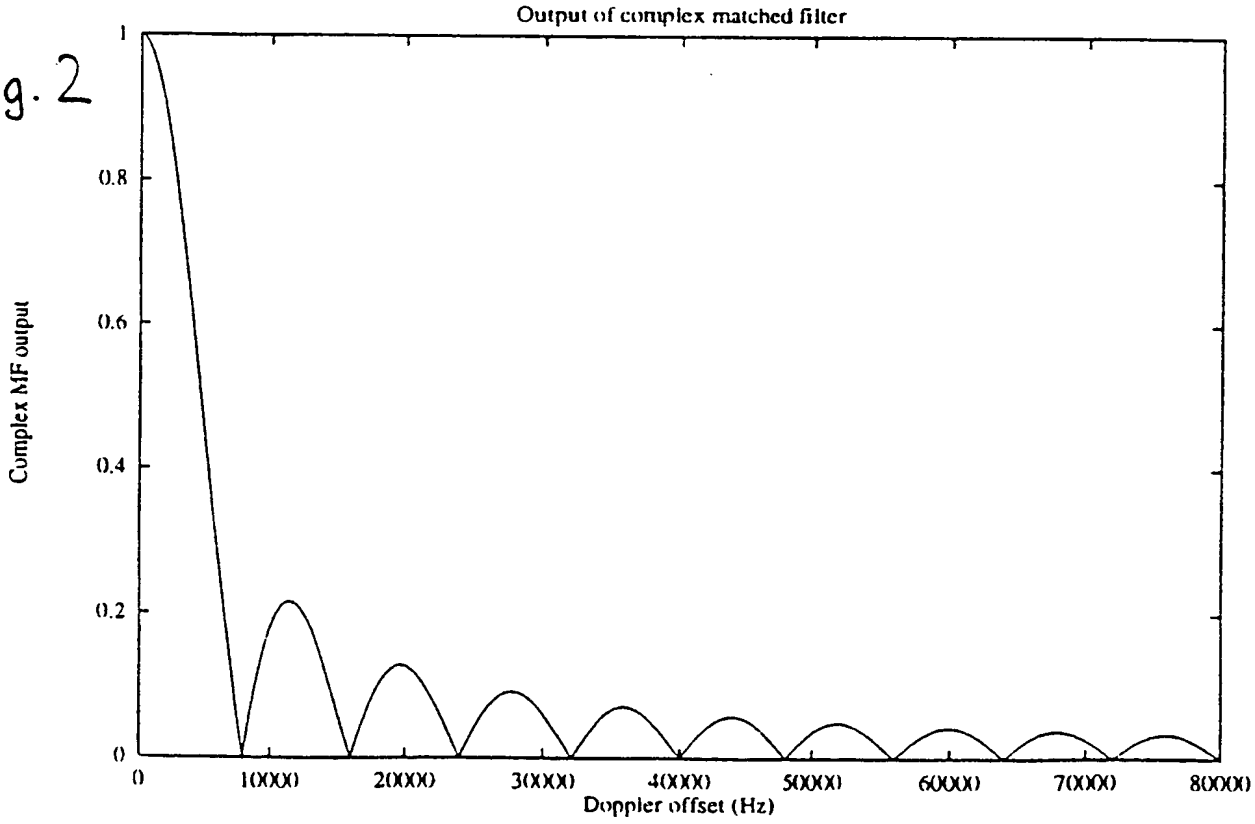

ΔT
Δt
ΔF
Δf
Correct code phase and Doppler

Fig. 2


Output of complex matched filter
Complex MF output
Doppler offset (Hz)
0
0.2
0.4
0.6
0.8
1
0
1(XXX)
2(XXX)
3(XXX)
4(XXX)
5(XXX)
6(XXX)
7(XXX)
8(XXX)

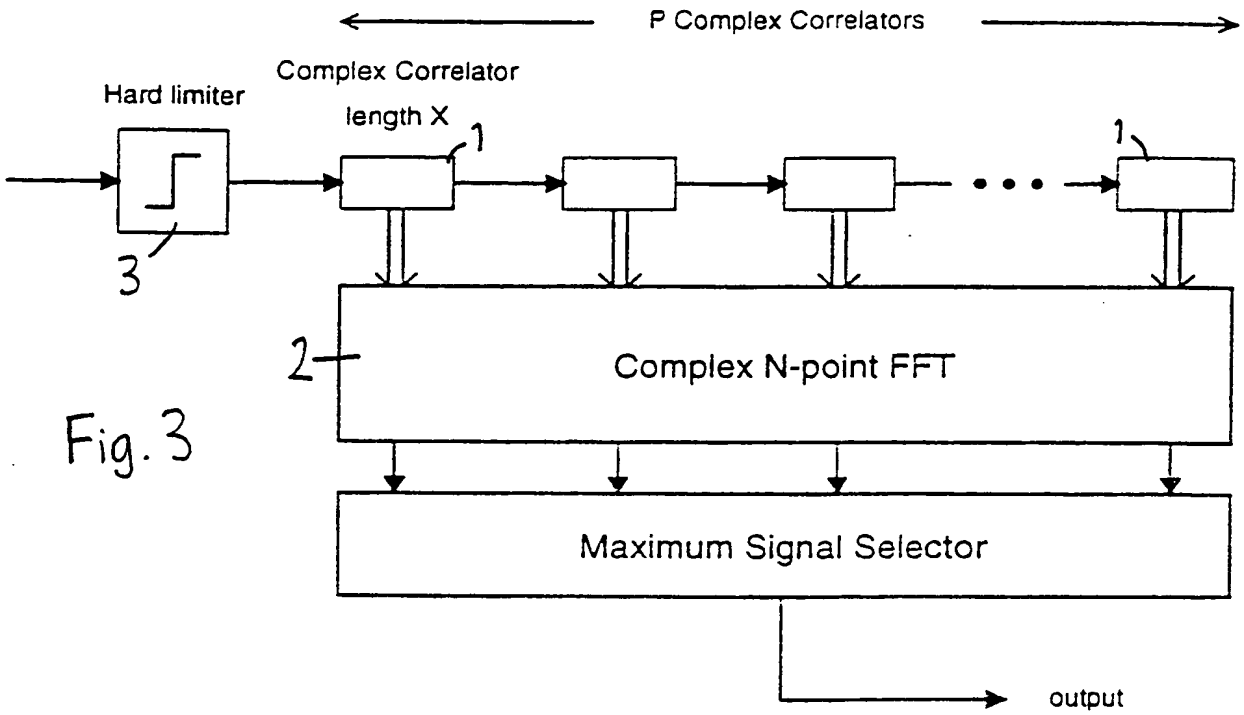

P Complex Correlators
Complex Correlator
length X
Hard limiter
1
1
3
2
Complex N-point FFT
Maximum Signal Selector
output

Fig. 3

Fig. 4

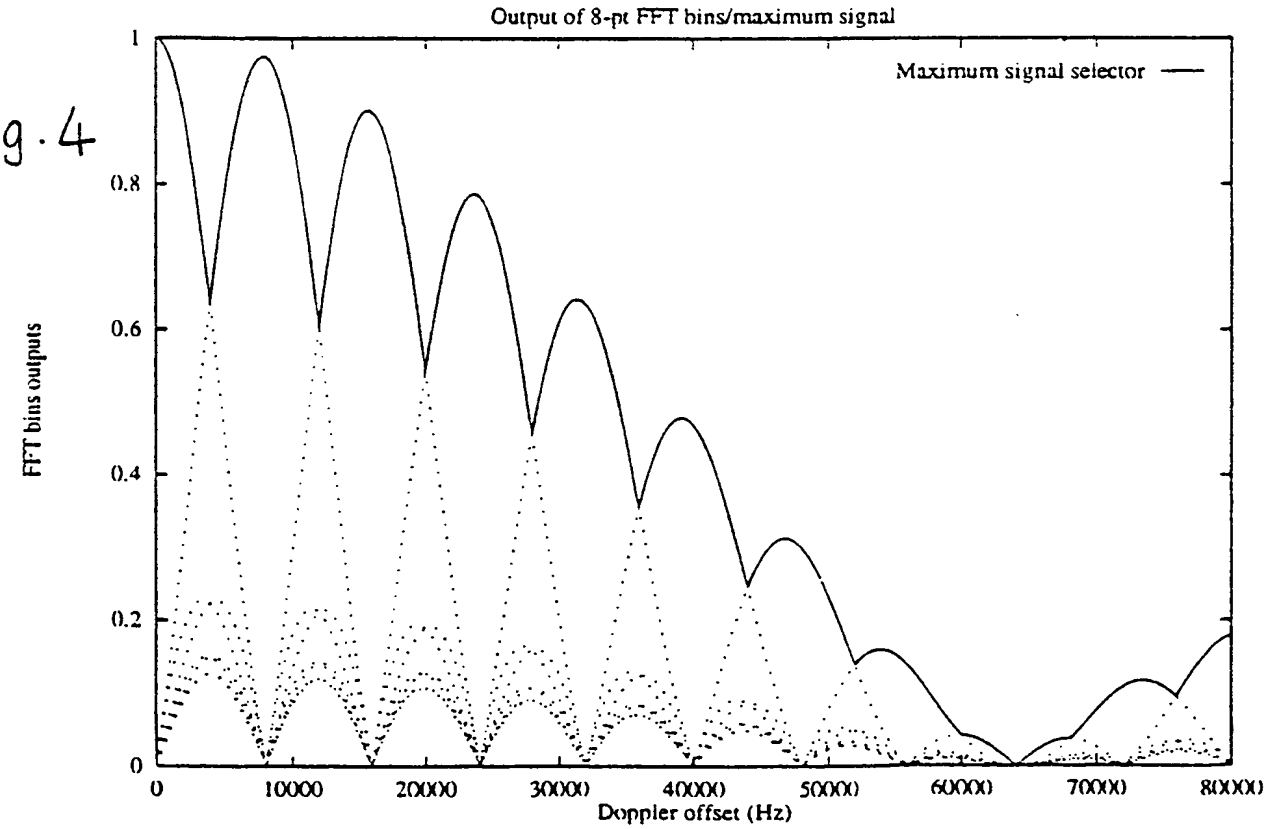

Output of 8-pt FFT bins/maximum signal
Maximum signal selector
FFT bins outputs
1
0.8
0.6
0.4
0.2
0
0
10000
20000
30000
40000
50000
60000
70000
80000
Doppler offset (Hz)

Fig.5

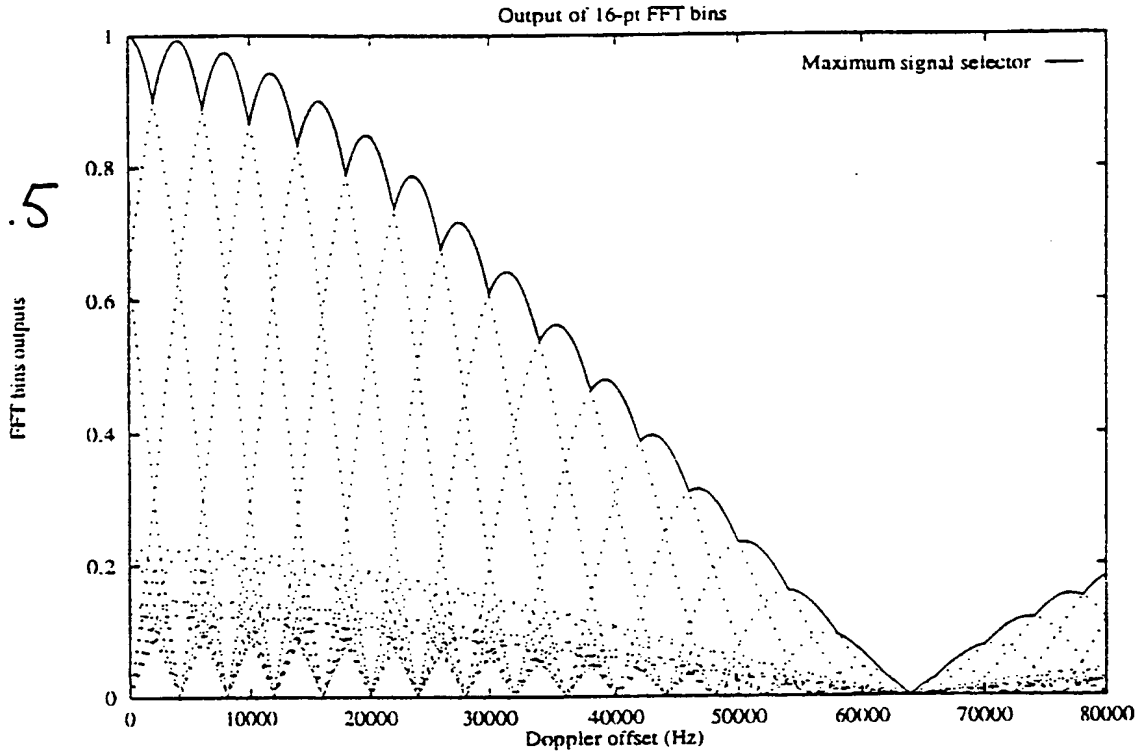

Output of 16-pt FFT bins
Maximum signal selector
FFT bins outputs
Doppler offset (Hz)
0
0.2
0.4
0.6
0.8
1
0
10000
20000
30000
40000
50000
60000
70000
80000

Fig.6

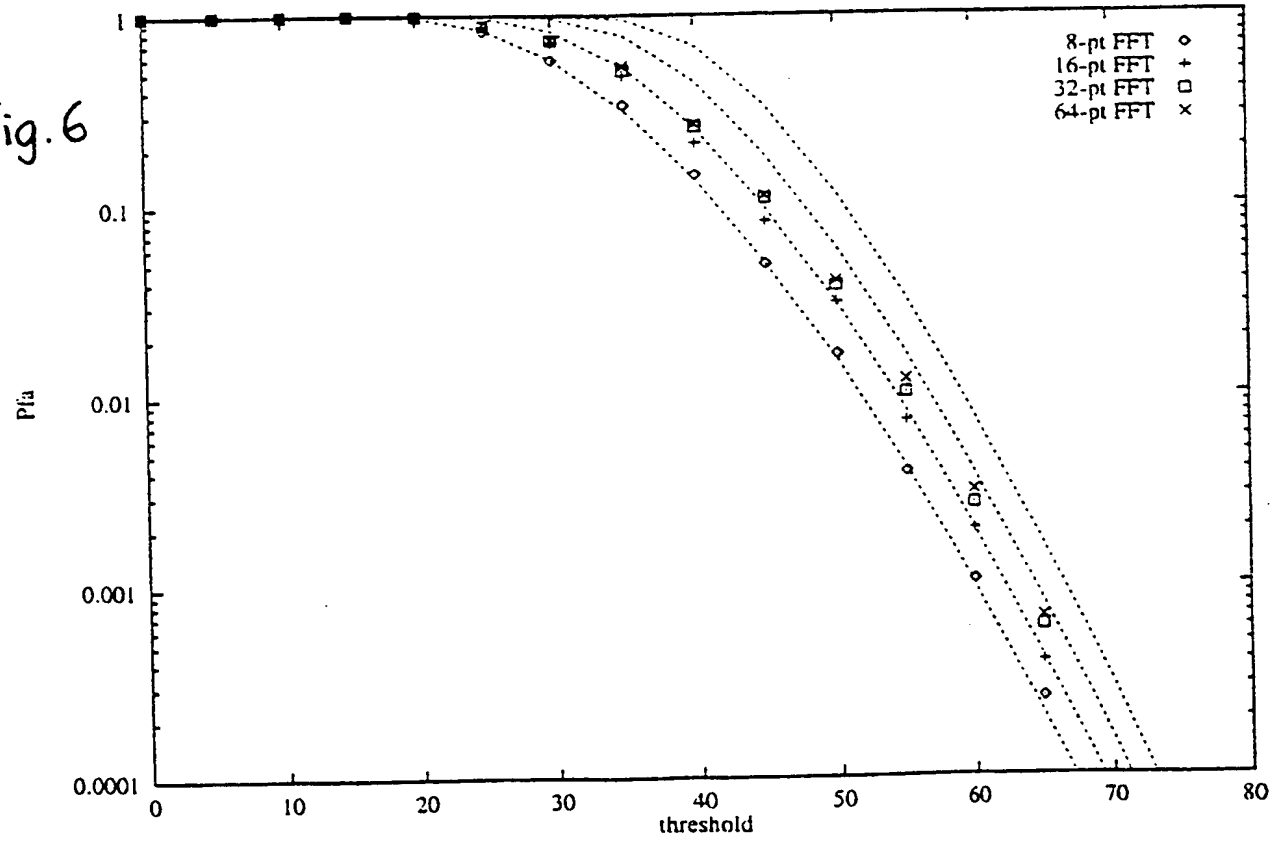

8-pt FFT
16-pt FFT
32-pt FFT
64-pt FFT
Pfa
threshold
1
0.1
0.01
0.001
0.0001
0
10
20
30
40
50
60
70
80

Fig.7

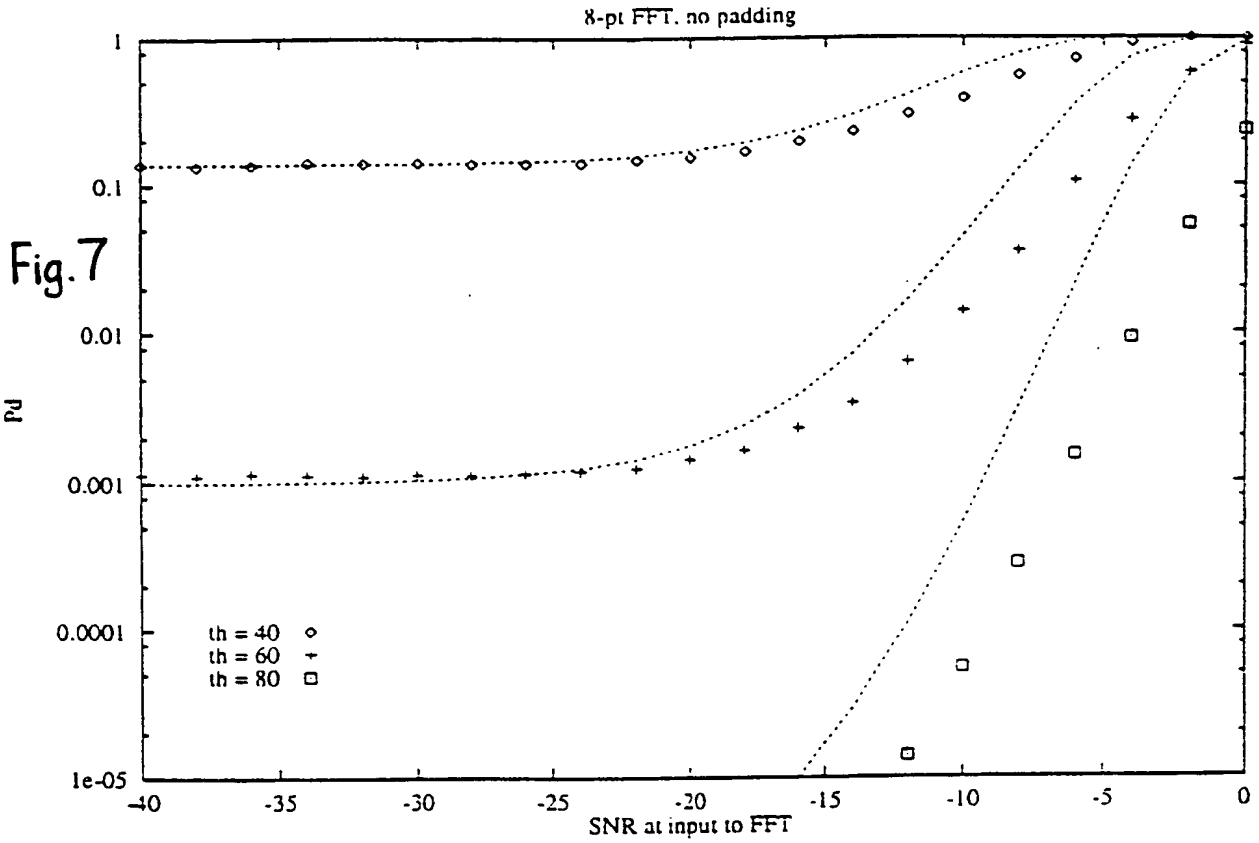

8-pt FFT, no padding
Pd
SNR at input to FFT
th = 40
th = 60
th = 80
1
0.1
0.01
0.001
0.0001
1e-05
-40
-35
-30
-25
-20
-15
-10
-5
0

Fig.8

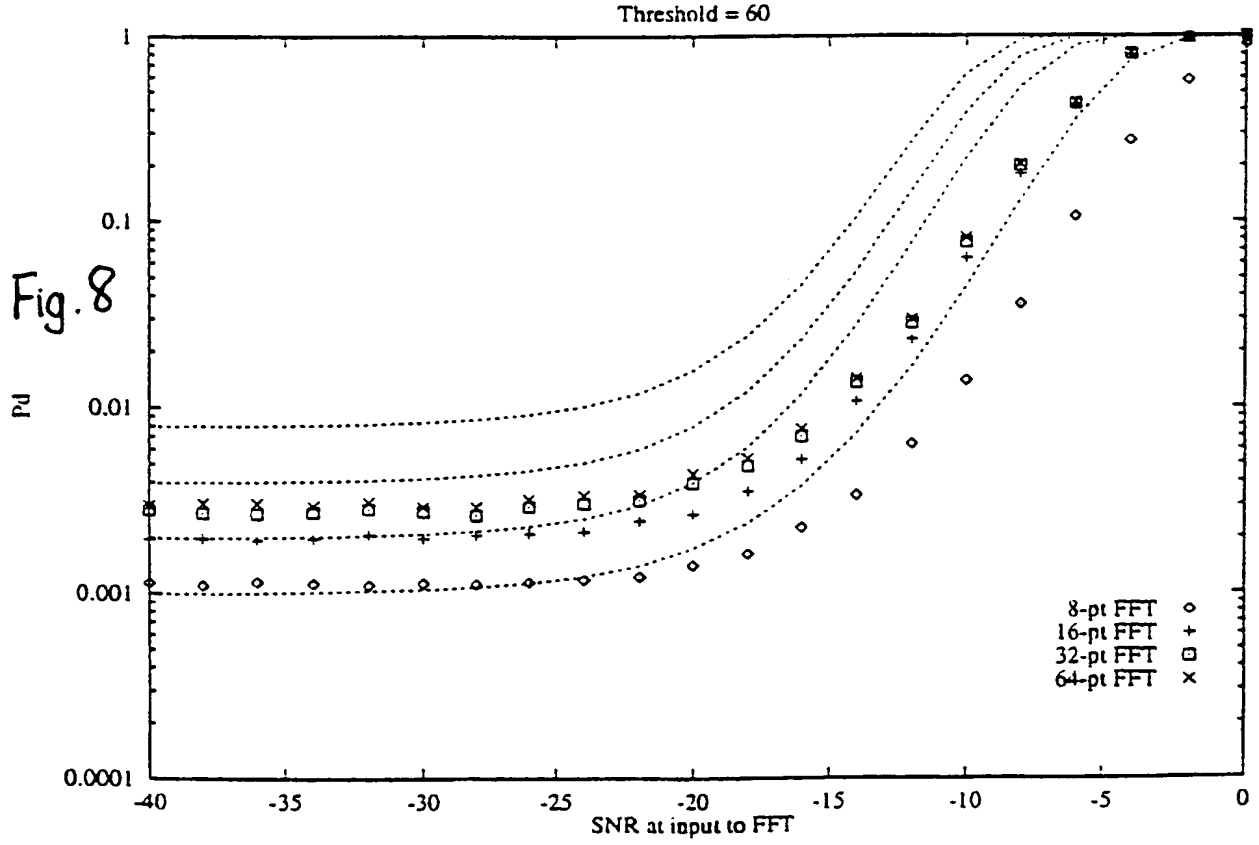

Threshold = 60
Pd
SNR at input to FFT
8-pt FFT
16-pt FFT
32-pt FFT
64-pt FFT
1
0.1
0.01
0.001
0.0001
-40
-35
-30
-25
-20
-15
-10
-5
0

Fig. 9

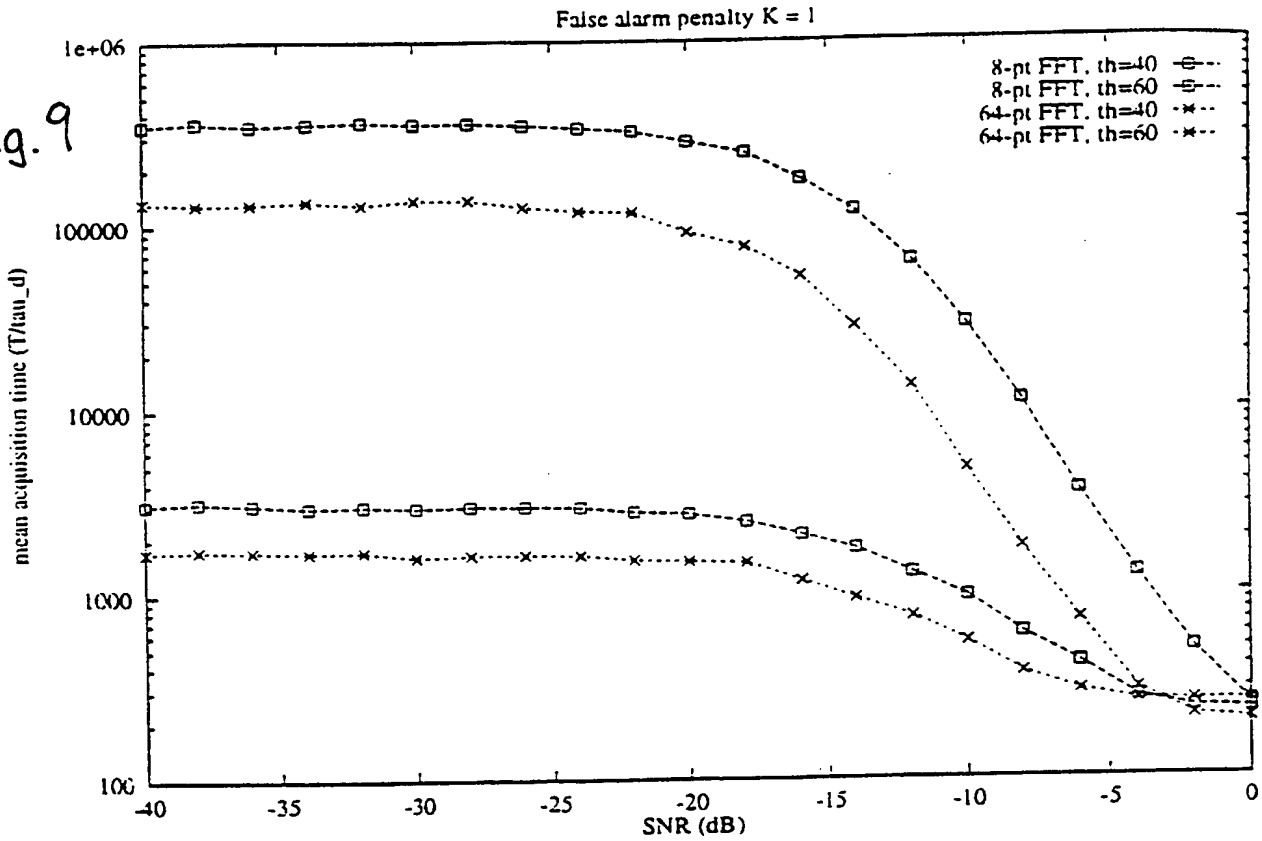
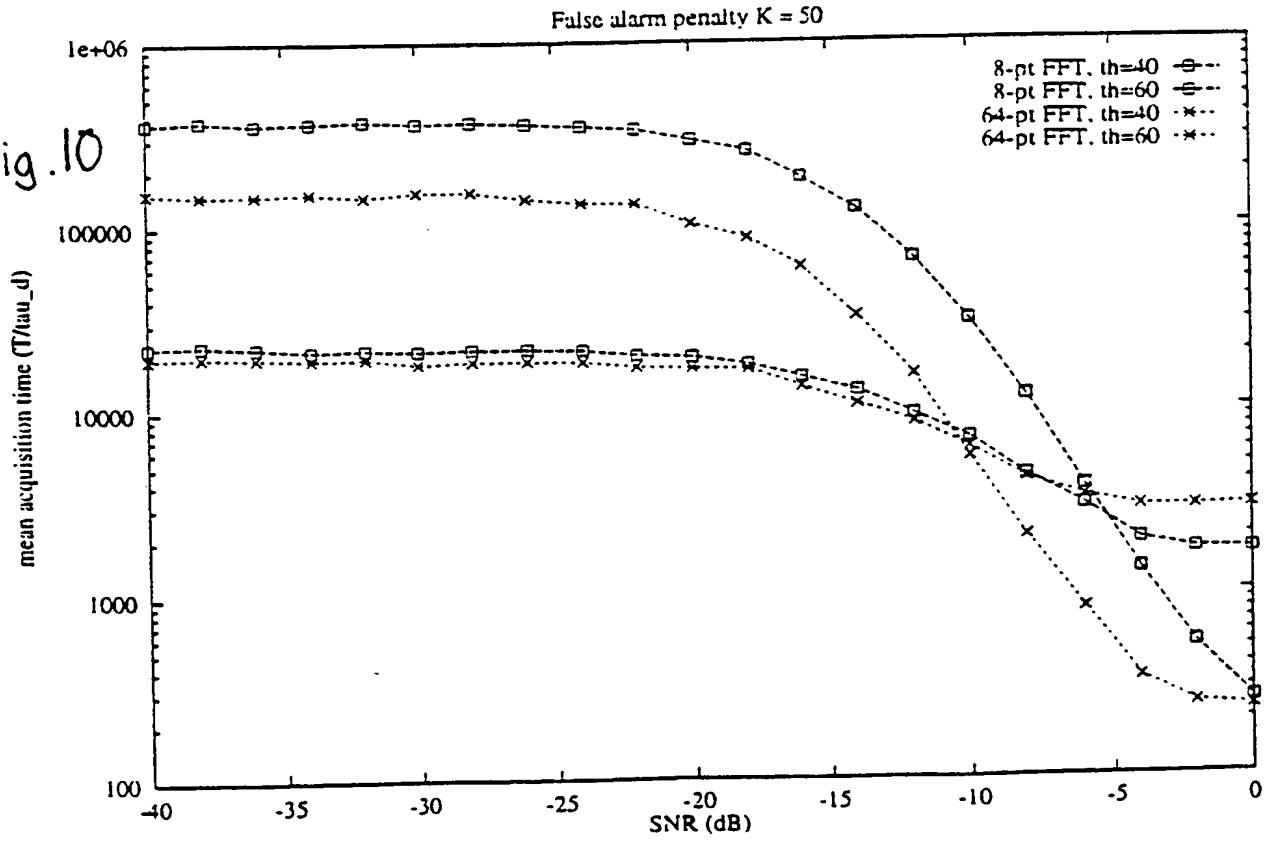

False alarm penalty K = 1
8-pt FFT, th=40
8-pt FFT, th=60
64-pt FFT, th=40
64-pt FFT, th=60
mean acquisition time (T/tau_d)
SNR (dB)
1e+06
100000
10000
1000
100
-40
-35
-30
-25
-20
-15
-10
-5
0

Fig. 10


False alarm penalty K = 50
8-pt FFT, th=40
8-pt FFT, th=60
64-pt FFT, th=40
64-pt FFT, th=60
mean acquisition time (T/tau_d)
SNR (dB)
1e+06
100000
10000
1000
100
-40
-35
-30
-25
-20
-15
-10
-5
0